end of a line. It also contributed to system stability but could not control power flow.

The second generation of FACTS devices -- such as the Thyristor-Controlled Series Capacitor (TCSC) -- uses thyristors to control a capacitor bank connected in series with a line, thus enabling a utility to increase power flow on particular lines over longer distances. Testing of the first single-phase TCSC began in 1991 by American Electric Power Co. In 1992, the Western Area Power Administration installed a three-phase TCSC that enabled them to increase the capacity of a transmission line from 300 MW to 400 MW. The world's largest TCSC, which has a full range of features, has been operating at Bonneville Power Administration since 1993.

A new advanced power transmission control system technology, called a static condenser (STATCON), was dedicated last November at Tennessee Valley Authority's (TVA) Sullivan substation (Figure 2). This third-generation FACTS controller provides voltage support to a transmission line by generating or absorbing reactive power through an all-electronic shunt connection. The system can respond quickly to damp major disturbances on the power system. This demonstration of a +/- 100 Mvar STATCON will enable TVA to avoid building a new 161-kV transmission line into the Johnson City area. This saved TVA about $ 80 million by not having to build a new 161-kV line costing $ 100 million.

The STATCON system (Figure 3) was developed by Westinghouse Electric Corp. with EPRI and TVA funding. It improves power flow through the electric transmission grid at lower costs than existing systems.

"From a consumer's standpoint, STATCON could potentially help lower the cost of electricity and provide the high-quality power needed by sensitive equipment such as computers," said Karl Stahlkopf, vice president of EPRI's Power Delivery Group. "From a utility's standpoint, STATCON provides a vital competitive advantage for confronting an era of deregulation," he added.

Deregulation, which would allow further open access to the electric transmission industry, would increase the number of electricity transfers. Bulk power, wholesale and transfers already account for 40 percent of all electricity generated and are expected to increase significantly (Figure 4). These transfers are beyond the original design capabilities of the existing power grid.

STATCON redirects current flow and raises flow limits on transmission networks in a fraction of a cycle, and helps smooth out disturbances before they reach sensitive customer equipment.

"Solid-state electronic devices, like STATCON, can increase the operational reliability of our transmission system while decreasing capital and maintenance cost," said Bill Museler. TVA vice president Transmission/Power Supply Group. "This demonstration enables TVA to avoid installing an additional transformer hank at the Sullivan substation and possibly avoid building a new line in the future," he added.

Development of STATCON has been made possible by the availability of a new generation of solid-state electronic switch called the gate-turn-off thyristor, or GTO. Use of GTOs enables the static condenser to regulate voltage without expensive external capacitors or reactors to avoid power disruption.

Electric Light & Power,

March, 1996

Tests at the Sullivan substation make this the most recent accomplishment in EPRI's Flexible ac Transmission System (FACTS) technology. FACTS enables utilities to better direct power flow and increase line capacity. The prototype equipment was designed, manufactured and tested at the Westinghouse Science and Technology Center in Pittsburgh, Pa.

"Our new technology gives faster and more precise control of power flow," said Aris Melissaratos. Westinghouse vice president for science, technology and quality. "In addition, we estimate that the STATCON will need about 60 percent less real estate and installation labor then conventional control equipment."
The STATCON at TVA is rated at 200 Mvar with an output that is continuously variable from minus 100 Mvar to plus 100 Mvar.

In the future, STATCON may be used to connect a stored energy source such as battery bank or superconducting coil to a power line and thus supply real power to protect critical loads during outages.

As construction of new transmission lines becomes more difficult, utilities are looking for better ways to control and optimize their existing power systems," Stahlkopf said.

AEP's control device

The American Electric Power Co. has approved plans to build the world's first demonstration of a major new type of electronic-transmission-system control device called the Unified Power Flow Controller (UPFC).

The UPFC technology was developed jointly by Westinghouse Electric Corp. and EPRI. AEP will build and operate the UPFC, integrating the new technology into its transmission system, one of the largest and most reliable extra-high voltage transmission networks in the world.

The first section of the UPFC -- a 160-Mvar shunt device for voltage support (essentially a STATCON, when operating alone) will be installed by the end of 1996 at AEP's Inez Substation in eastern Kentucky, where it will help increase power transfer into a coal-mining area that has experienced steady electricity load growth. The UPFC will also provide voltage support to improve transmission system reliability in the heavily industrialize Tri-State are further north, where the border of Ohio, Kentucky and West Virginia meet.
Because of recent federal and state actions to deregulate transmission services, many utilities are looking for better ways to bolster reliability and control the flow of power on their transmission system in anticipation of increasing power flows. The UPFC has the unique capability of simultaneously controlling all the major electrical characteristics that determine power flow over transmission lines.

"Traditionally, utilities controlled power flow by changing the way the dispatched generators," explains Mark Wilhelm, director of EPRI's Substations, System Operations & Storage Business Unit. "With deregulation, that option is going to become considerably more difficult. A much more direct method is needed to control the flow of power on specific lines and thus better utilize transmission assets in response to rising demand. UPFC supplies that capability."

Electric Light & Power,

March, 1996

"We are exploring the feasibility of deploying several UPFCs in a centrally controlled fashion across our seven-state transmission system," says Bruce Renz, AEP Vice President of Transmission and Distribution Services. "These revolutionary devices will enable us to increase power transfer to take advantage of new competitive opportunities while improving the quality of service to our customers by making the existing network even more reliable."

The UPFC represents about $ 24 million of a total $ 90 million transmission upgrading program AEP has launched in the eastern Kentucky areas. EPRI is contributing about $ 2 million for the demonstration of this technology, with further co-funding from Westinghouse. A new kind of thyristor switch designed for use in the UPFC is expected to find other utility applications as well.

The UPFC technology was also developed through EPRI's decade-long FACTS program. Stahlkopf said, "In an increasingly competitive era for the electric power industry, utilities need more sophisticated technologies to cut costs and maximize use of the transmission assets. "The UPFC offers an unprecedented opportunity to control power flow directly, preventing overloads and increasing overall system throughput."

A second section, a 100-Mvar series device to add power-flow control capability will be connected to a new 138-kV transmission line when both are completed in 1997. By combining these function, the Inez UPFC will help increase power transfer into a coal mining area that has experienced steady load growth.

Another inverter-based FACTS system that is a candidate for development and demonstration include the Static Synchronous Series Compensator (SSSC) developed by Westinghouse. It is a solid-state voltage source inverter connected in series with the transmission line via a series insertion transformer. The SSSC is an extremely powerful tool for power flow control because it is able to modify the effective transmission line reactance independently of the line current flow. Also, the SSSC has the capability to reverse power flow.

The same inverters as those used on this and the other systems can be applied as the Energy Storage Interface allowing stored energy from technologies such as Superconducting Magnetic Energy Storage (SMES), batteries, or fuel cells to be instantaneously injected into or absorbed from the system. A voltage-sourced inverter, or dc-to-ac converter, utilizes the constant dc bus voltage to produce sinusoidal three-phase voltages suitable for interfacing with the utility transmission system.

Closed-loop control coordinates the operation of dc-to-dc converter and the inverter to permit the exchange of real and reactive power between the utility network, the dc bus and the energy storage.

Damping control of power systems

Transmission lines generate and absorb reactive power. Since the transmitted load varies considerably from one hour to the next, the reactive power balance of the line also varies. A rapidly operating static var compensator (SVC) can continuously control the reactive power throughout the entire absorption and generation range. The operating range is often increased by breaker-switched reactors or capacitors controlled from the SVC.

Electric Light & Power,

March, 1996

Between electric power systems that are interconnected via a relatively weak line, power oscillation problems often arise. Damping is then often the factor that determines the transmission capacity. SVC increases the damping actions so that more power can be transmitted. The installation of new lines can therefore by avoided or postponed.

Engineers at ABB's Transmission Technology Institute are working with utilities worldwide to improve the operation and control of today's ac and dc transmission systems. One such challenge is the interactions between the various control systems.

Engineers must constantly re-evaluate the effectiveness of feedback control policies for damping low-frequency electro-mechanical oscillations. The design of power system damping controllers such as the power system stabilizer (PSS) and the static var compensator (SVC) damping controls has traditionally been performed based on single-loop classical design concepts.

The uncertainty in the system operation is normally accounted for by repeated testing and redesign. The interaction between several controllers is generally neglected in the design phase but studied during the analysis phase. This design methodology has served the industry well in most cases, but might face difficulties in the near future.

Utilities in Europe and the North America are moving toward a market-oriented industry in which the dispatch of the generation facilities and the flow patterns on the transmission network might face more frequent and drastic changes than are observed under a monopolistic utility structure.

The proliferation of more control systems combined with higher levels of transmission loading will instigate higher levels of interactions between the various control systems. This will challenge the current control design methodologies and might render them ineffective in some cases.

In a deregulated power industry, more controllers will be pressed into service with overlapping regions of operations. In such situations, according to ABB Power T&D Company Inc. engineers, it becomes important to consider effects such as controller interaction and appropriate tuning of controller parameters. In the absence of automated tools to perform such studies, the engineering cycle-time for the design of controllers and evaluation of performance takes anywhere from a few days to weeks.

A program at ABB's Transmission Technology Institute addresses this issue. The program enables a user to set up power system models and perform a variety of useful analysis studies. The program also enables the user to specify uncertainty models representing a variety of operating conditions, as well as design robust controllers that meet guaranteed stability margins.

Some of the benefits of using modern power electronic technology include:

* stabilizing voltages in weak systems,

* reducing transmission losses,

* increasing the transmission capacity,

* increasing the transient stability limit,

* increasing damping of small disturbances,

* improving voltage control and stability, and

* damping power swings.

Optical voltage sensor

A research team headed by ABB Power T&D Company Inc. and composed of the Empire State Electric Energy Research Corp., Tennessee Valley Authority and New York Power Authority has developed the Electro-Optic Voltage Transducer System (EOVT) for use on 345-kV systems.

This device won the "R&D 100" award for 1994 -- a top honor in the field of applied research. The EOVT is a state-of-the-art advancement in precision-voltage sensing at 69 kV through 765 kV. The system uses light to accurately measure high voltage on electric utility transmission systems. The output is connected to either a revenue meter or to a protective relay. The optical system replaces oil-filled voltage transformers. The new design eliminates the need for oil, removes the possibility of violent failures and is smaller, lighter and more economical overall than conventional technologies. The EOVT system includes sensors located in the substation yard, an electronics module in the control house and the optical fiber that connects the sensor and module.

The operational process begins when the EOVT system launches light from the electronics module. The light then travels through the optical fiber to the optical sensor assembly where the light next passes through a polarizer into the crystal or sensor. One end of the sensor is connected to the high-voltage electrode and the other end to the ground electrode. The line-to-ground voltage across the sensor causes the intensity of the light to vary in an accurate relationship to the voltage in the primary. The light then returns to the electronic module where the light signal is converted into an electrical signal representing the primary voltage.

GRAPHIC: Figure 1, A whole array of new solid-state electronic devices have been developed to help control power flow in today's transmission grid and substations similar to this one; Figure 2, The three-high stacking arrangement of the solid-state electronic devices called STATCON for static condensors was developed by Westinghouse with Electric Power Research Institute and Tennessee Valley Authority funding. STATCON improves power flow through the transmission grid while lowering costs; Figure 3, Wave from of 48-pulse inverter, Output voltage and current waveforms of a 48-pulse inverter generating reactive (capacitive) power; Figure 4, Growth in bulk power transactions, Some 40 percent of the electricity generated in the United States is now sold on the wholesale market -- a four-fold increase in a decade. With new players, such as power brokers, etc., the growth may accelerate even more in the next decade, Source: AGA/EEI

STORIES

Electrical World

April, 1996

SECTION: SPECIAL T & D FEATURE; Vol. 210, No. 4; Pg. 27

LENGTH: 852 words

HEADLINE: CON EDISON INCREASES USE OF ENVIRONMENTALLY FRIENDLY CABLE

BODY:

Consolidated Edison Co of New York Inc is well known for its extensive use of high-pressure fluid-filled (HPFF) cable. According to Juan Dominguez, manager, transmission feeder engineering, the company now has about 650 circuit miles of HPFF cable installed, plus another 50 miles of low-pressure, fluid-filled cable (LPFF). But fluid-filled cable always presents the environmental hazard of fluid leaks, a problem that is especially critical when the cable passes over or under a waterway. An additional environmental drawback of LPFF cable is that a lead sheath is used to contain the dielectric fluid.

For these reasons, Con Edison has been increasing its use of solid dielectric cables since an initial 5-mi installation in 1994. Dominquez reports that 110,000 ft of 138-kV cables will be installed in 1996 in Brooklyn. In 1997, two 138-kV feeders leading form Westchester to Manhattan will increase the usage by 250,000 ft. This spring, the Queensboro Bridge connecting Manhattan with the borough of Queens will have new solid-dielectric cables installed under it (Fig 1).

Cross-linked polyethylene (XLPE) cables are purchased from Alcatel, Canada Wire Inc, Toronto, Ont Canada; Nokkia Cables USA Inc, Albany, NY; Pirelli Cable Corp, Que, Canada; and Silec, Montereau, France. Other manufacturers have been approved, but the utility has not yet purchased cable from them. Dominguez notes that all XLPE cable for transmission voltages is made overseas, but with environmental concerns now at a peak, US cable manufacturers will soon enter the field.

A feeder using solid-dielectric cable consists of a steel pipe containing three single-conductor cables with splices located at intervals of approximately 2000 ft. In some cases, the solid-dielectric cables can be pulled into the pipe that originally contained the HPFF cable. The pipe is filled with nitrogen gas at 15 psig to eliminate moisture ingress. No dielectric fluid or pumping plants are required. Although the cost per foot of the solid-dielectric cable is higher than paper-insulated, fluid-filled cable, the cost for the completed system is comparable.

Eliminate lead at low voltages For years, Con Edison has operated one of the largest network systems in the world, using paper-insulated, lead-covered cable (PILC) at 13.8 and 27 kV. Solid-dielectric EPR cables were later found to better survive the high temperatures encountered by primary network feeders and this material gradually replaced paper insulation in cables. But these solid-dielectric cables were also enclosed in a lead sheath to provide a hermetic seal against petroleum products, salt, and other chemicals. The lead sheaths were partly a carry over from PILC, but Louis Rana, chief distribution engineer, points out that a metal shield is the only way to provide an impervious shield for the cable. Plastic jackets inevitably allow some migration of moisture and will eventually break down in the presence of hydrocarbons. The lead sheaths also provide fault-current carrying capacity and simplify transition splices to existing PILC.

But lead presents an environmental problem of its own and Con Edison has long been searching for an alternative protective sheath. Lead can be highly toxic when ingested or inhaled. Improper handling and disposal of lead waste are harmful to both humans and the environment. As a result, disposal cost of manhole debris containing lead can be three times the cost of non-hazardous waste.

Recently, Con Edison, in partnership with the Okonite Co, Ramsey, NJ, developed a continuously welded bronze sheath to provide an environmentally benign, metallic moisture seal for solid dielectric cables. The new cable, known as C-L-X (Fig 2), is similar to a nonflammable, corrugated stainless steel cable developed by Okonite and Kabelmetal Electro, Germany, for the industrial market and shipboard use in naval vessels. The new cable has all the physical properties of a lead-sheathed cable -- including mechanical integrity and fault-current-carrying capability -- with none of the environmental drawbacks of lead (Fig 2). Three different types of splices, manufactured by 3M, St. Paul, Minn; Raychem Corp, Newark, Del; and Elastimold, Hackettstown, NJ, can be used with the new cable.

The first three sections of C-L-X cable were installed in the Bronx in 1995 (Fig 3). In January of this year, as part of a network reinforcement program, three additional sections of triplexed cable were installed in the express run of a 13-kV feeder from a substation supplying the Plaza Network in midtown Manhattan. The cables are installed in precast concrete ducts in the midst of steam mains and the subway system.

Future use of the new cable is planned for installations where contact with oil or other hydrocarbons is a possibility. According to Rana, about one-third of Con Edison's network cables meet that criterion. Now on order are 12,000 triplexed circuit-ft of 15-kV, 750-kcmil, compact round copper and 12,000 triplexed circuit ft of 27-kV, 500-kcmil. Cost is comparable to the EPR-insulated, lead-sheathed cable.

GRAPHIC: Table, Photograph: 1. Solid dielectric XLPE cable was recently installed under the Queensboro Bridge spanning New York's East River, eliminating the risk of fluid spills ; Photograph: 2. Bronze-sheathed cable with TPR jacket is insulated with ethylene propylene rubber ; Photograph: 3. Lead-free cables are now being used in Con Edison's extensive network system. Bottom cable has jacket removed

LANGUAGE: ENGLISH

LOAD-DATE: April 25, 1996

STORIES

Electrical World

February, 1992

SECTION: TRANSMISSION & DISTRIBUTION; TRANSMISSION UPGRADE; Vol. 206, No. 2; Pg. 63

LENGTH: 534 words

HEADLINE: Forced-cooled cable serves urban area

BYLINE: Greg Paula, Associate Editor

BODY:

Faced with the need to transfer additional power between two substations, Commonwealth Edison Co sought a way to upgrade the existing cable. The utility solved the problem economically by employing an old technology: forced cooling.

The existing 138-kV, oil-filled, pipe-type, 6.5-mi power cable between Commonwealth Edison's University and Taylor substations can no longer meet the utility's needs. Options available to increase the capacity of the line included installing an additional, parallel cable and removing the existing cable and replacing it with a higher-rated one.

However, both of these alternatives to upgrading would have required extensive capital and labor expenditures.

Commonwealth Edison chose a third option: forced cooling, which uses oil to remove heat from the cable, thereby increasing the amount of power it can transfer. Forced-cooled cables first were installed in the 1930s. They were relatively common when electric demand was growing quickly. The cooling capability was employed mostly during emergencies, not for normal operations. However, when the growth in electric demand began to slack off in the mid 1970s, forced-cooled cables became less prominent. The Commonwealth Edison project reportedly is the first forced-cooled cable constructed in almost 20 years. Pirelli Jerome Inc, Beaufort, SC, is designing, manufacturing, and installing the $ 3-million project.

Normally, when adding cooling capability to a pipe-type cable, a parallel return pipe is required. This pipe does not have a conductor within it and only is used to recirculate the oil. Commonwealth Edison foresaw the need for eventual upgrading when it first installed the cable. Accordingly, it installed a return pipe at the time of original construction, even though it was not needed for normal pipe-type operation. The resulting configuration permits the utility to upgrade the cable by simply adding the necessary cooling equipment at both ends of the cable; no modifications to the cable itself are needed.

According to the utility, adding cooling capability is far less expensive than the alternatives. Much of the saving comes from not having do any work on the cable itself. Nevertheless, analysis indicates that forced cooling would have been more economical than other options even if the return pipe had not been installed beforehand.

The system will employ two types of cooling equipment: air-cooled heat exchangers at both ends of the cable (figure) and refrigeration units at one end to cool the oil directly.

Cooling is not required all the time; equipment will function only when needed. On a cold day, for example, no cooling may be required. On a 60F day, pumping the oil through the air coolers might be sufficient to maintain proper oil temperature. On a very hot day -- when the cable needs to carry more power and the high ambient temperature makes air cooling less effective -- the refrigeration units might be needed as well. Automatic controls turn cooling equipment on and off, depending on the oil temperature.

According to the manufacturer, maintenance considerations for the cable will be basically the same as they were before the conversion. The only new components are the coolers and the pumps, which require minimal maintenance. "Indeed, the overall reliability of the cable probably will be better because the cooling system helps ensure that the oil temperature will never get too high," says Roy Fleckenstein, director of sales and engineering for Pirelli Jerome.

The necessary equipment currently is being installed. The normal summer rating will increase from 220 to 325 MVA; the 10-day emergency rating will be boosted from 270 to 400 MVA. The redesigned cable is expected to operate at its new capacity by this June.

GRAPHIC: Figure, Heat exchanger uses ambient air to cool the oil
LANGUAGE: ENGLISH

Transmission Structural Advancements

Product Manager: R. Michael McCafferty
Target: Overhead Transmission

Cut wood pole maintenance costs, and reduce outages caused by failed wood crossarms and poles. Development of structural components and hardware that have longer life than existing products, and provide comparable strength and value, will enable utilities to cut replacement and maintenance costs and reduce outages caused by failed wood poles. This research includes an evaluation and demonstration of a fiberglass, 115 kV, H-frame structure, an evaluation of causes of wood crossarm failures and suggestions for improvement, and develop methods for extending the life of existing wood arms.

[Overhead Transmission]

Table of Contents | Power Delivery

EPRI Search Home

Progressive Flexibility '97

Table of Contents | Power Delivery

NEXRAD for Local Wind and Ice Data

Product Manager: Paul F. Lyons
Target: Overhead Transmission

Reduce wind load and lower costs of line upgrades by improving the accuracy of local area wind predictions.

Data from the new NEXRAD radar has the potential to enable utilities-especially those with service areas subject to severe local storms-to reduce wind and ice load, and cut costs for system upgrades by improving the accuracy of local area wind maps. Local wind maps provide the greatest potential for reducing wind load. However, their accuracy is limited because they depend on data from scattered ground stations. NEXRAD provides superior data, but measurements begin 1000 to 3000 feet above ground level. This project will develop an algorithm to estimate conditions at 10 meters from the NEXRAD data, and develop an interface that allows the data to be used to make local wind maps.

[Overhead Transmission]

Table of Contents | Power Delivery

[EPRI Home | Search] Last Updated: 6/24/96

EPRI Search Home

Progressive Flexibility '97

Table of Contents | Power Delivery

Right-of-Way Vegetation Management

Product Manager: R. Michael McCafferty
Target: Overhead Transmission

Reduce vegetation management costs 10-20%, and reduce tree-caused line outages.
Locating dangerous trees and predicting their growth rate can help utilities reduce line outages and cut vegetation management costs by 10-20%. This project will develop methods for identifying existing and potential danger trees, and provide species-specific guidelines for predicting growth rates, based on soil and weather conditions. This information will help cut vegetation management costs by determining the degree and frequency of trimming needs. A report suggesting methods to optimize the use of vegetation management funds will also be prepared.

[Overhead Transmission]

Table of Contents | Power Delivery

[EPRI Home | Search] Last Updated: 6/24/96

Attachment 4

Compendium of Cites from
National Electric Safety Code
1997 Edition

223. Communications Protective Requirements

A. Where Required

Where communication apparatus is handled by other than qualified persons, it shall be protected by one or more of the means listed in Rule 223B if such apparatus is permanently connected to lines subject to any of the following:

1. Lightning
2. Contact with supply conductors whose voltage to ground exceeds 300 V
3. Transient rise in ground potential exceeding 300 V
4. Steady-state induced voltage of a hazardous level

NOTE: When communication cables will be in the vicinity of supply stations where large ground currents may flow, the effect of these currents on communication circuits should be evaluated.

B. Means of Protection

Where communication apparatus is required to be protected under Rule 223A, protective means adequate to withstand the voltage expected to be impressed shall be provided by insulation, protected where necessary by surge arresters used in conjunction with fusible elements. Severe conditions may require the use of additional devices such as auxiliary arresters, drainage coils, neutralizing transformers, or isolating devices.

224. Communication Circuits Located Within the Supply Space and Supply Circuits Located Within the Communication Space

A. Communication Circuits Located in the Supply Space

1. Communication circuits located in the supply space shall be installed and maintained only by personnel authorized and qualified to work in the supply space in accordance with the applicable rules of Sections 42 and 44.
2. Communication circuits located in the supply space shall meet the following clearance requirements, as applicable:
   a. Insulated communication cables supported by an effectively grounded messenger shall have the same clearances as neutrals meeting Rule 230E1 from communication circuits located in the communication space and from supply conductors located in the supply space. See Rules 235 and 238.
   b. Fiber-optic cables located in the supply space shall meet the requirements of Rule 230F.
   c. Open-wire communication circuits permitted by other rules to be in the supply space shall have the same clearances from communication circuits located in the communication space and from other circuits located in the supply space as required by Rule 235 for open supply conductors of 0–750 V.

   EXCEPTION: Service drops meeting Rule 224A3a and 224A3b may originate in the supply space on a line structure or in the span and terminate in the communication space on the served structure.
3. Communication circuits located in the supply space in one portion of the system may be located in the communication space in another portion of the system if the following requirements are met:
   a. Where the communication circuit is at any point located above an energized supply conductor or cable, the communication circuit shall be protected by fuseless surge arresters, drainage coils, or other suitable devices to prevent the communication circuit voltage from normally exceeding 400 V to ground.

   NOTE: The grades of construction for communication conductors with inverted levels apply.
   b. Where the communication circuit is always located below the supply conductors, the communication protection shall meet the requirements of Rule 223.
   c. The transition(s) between the supply space and the communication space shall occur on a single structure; no transition shall occur between line structures.

   EXCEPTION: Service drops meeting Rule 224A3a and Rule 224A3b may originate in the supply space on a line structure or in the span and terminate in the communication space on the served structure.

in

Table 235-5
Vertical Clearance Between Conductors at Supports
(When using column and row headings, voltages are phase to ground for effectively grounded circuits and those other circuits where all ground faults are cleared by promptly de-energizing the faulted section, both initially and following subsequent breaker operations. See the definitions section for voltages of other systems. See also Rules 235C1, 235C2, and 235F.)

Conductors and cables usually at lower levels	Conductors and cables usually at upper levels			
	Supply cables meeting Rule 230C1, 2, or 3; neutral conductors meeting Rule 230E1, communications cables meeting Rule 224A2a (in)	Open supply conductors		
		0 to 8.7 kV (in)	Over 8.7 to 50 kV	
			Same utility [8] (in)	Different utilities [9] (in)
1. Communication conductors and cables a. Located in the communication space	40 [1,6]	40	40	40 plus 0.4 per kV [7] over 8.7 kV
b. Located in the supply space	16 [10,11]	16 [2,11]	40 [11]	40 plus 0.4 per kV [7] over 8.7 kV
2. Supply conductors and cables a. Open conductors 0 to 750 V; supply cables meeting Rule 230C1, 2, or 3; neutral conductors meeting Rule 230E1	16 [10]	16 [3]	16 plus 0.4 per kV [7] over 8.7 kV	40 plus 0.4 per kV [7] over 8.7 kV
b. Open conductors over 750 V to 8.7 kV		16 [3]	16 plus 0.4 per kV [5,7] over 8.7 kV	40 plus 0.4 per kV [7] over 8.7 kV
c. Open conductors over 8.7 to 22 kV (1) If worked on alive with live-line tools and adjacent circuits are neither de-energized nor covered with shields or protectors			16 plus 0.4 per kV [7] over 8.7 kV	40 plus 0.4 per kV [7] over 8.7 kV
(2) If not worked on alive except when adjacent circuits (either above or below) are de-energized or covered by shields or protectors, or by the use of live-line tools not requiring line workers to go between live wires			16 plus 0.4 per kV [4,7] over 8.7 kV	16 plus 0.4 per kV [4,7] over 8.7 kV
d. Open conductors exceeding 22 kV, but not exceeding 50 kV			16 plus 0.4 per kV [4,7] over 8.7 kV	16 plus 0.4 per kV [4,7] over 8.7 kV

[1] Where supply circuits of 600 V or less, with transmitted power of 5000 W or less, are run below communication circuits in accordance with Rule 220B2, the clearance may be reduced to 16 in.

[2] This shall be increased to 40 in when the communication conductors are carried above supply conductors unless the communication-line-conductor size is that required for Grade C supply lines.

[3] Where conductors are operated by different utilities, a vertical clearance of not less than 40 in is recommended.

[4] These values do not apply to conductors of the same circuit or circuits being carried on adjacent conductor supports.

[5] May be reduced to 16 in where conductors are not worked on alive except when adjacent circuits (either above or below) are de-energized or covered by shields or protectors, or by the use of live line tools not requiring line workers to go between live wires.

[6] May be reduced to 30 in for supply neutrals meeting Rule 230E1 and cables meeting Rule 230C1 where the supply neutral or messenger is bonded to the communication messenger.

[7] The greater of phasor difference or phase-to-ground voltage; see Rule 235A3.

[8] Example: For a 50 kV-to-ground conductor above a 22 kV-to-ground conductor, the required clearance is 16 in [+] 25 in [=] 41 in when the conductors are 180° out of phase.

[9] Example: For a 50 kV-to-ground conductor above a 22 kV-to-ground conductor, the required clearance is 40 in [+] 25 in [=] 65 in when the conductors are 180° out of phase.

[10] No clearance is specified between neutral conductors meeting Rule 230E1 and insulated communication cables located in the supply space and supported by an effectively grounded messenger.

[11] No clearance is specified between fiber-optic—supply cables meeting Rule 230F1b and supply cables and conductors.

1. Cables that are supported on or cabled together with an effectively grounded bare messenger or neutral, or with multiple concentric neutral conductors, where any associated neutral conductor(s) meet(s) the requirements of Rule 230E1 and where the cables also meet one of the following:
   a. Cables of any voltage having an effectively grounded continuous metal sheath or shield, or
   b. Cables designed to operate on a multi-grounded system at 22 kV or less and having semiconducting insulation shielding in combination with suitable metallic drainage.
2. Cables of any voltage, not included in Rule 230C1, covered with a continuous auxiliary semiconducting shield in combination with suitable metallic drainage and supported on and cabled together with an effectively grounded bare messenger.
3. Insulated, nonshielded cable operated at not over 5 kV phase to phase, or 2.9 kV phase to ground, supported on and cabled together with an effectively grounded bare messenger.

D. Covered Conductors

Covered conductors shall be considered bare conductors for all clearance requirements except that spacing between conductors of the same or different circuits, including grounded conductors, may be reduced below the requirements for open conductors when the conductors are owned, operated, or maintained by the same party and when the conductor covering provides sufficient dielectric strength to limit the likelihood of a short circuit in case of momentary contact between conductors or between conductors and the grounded conductor. Intermediate spacers may be used to maintain conductor spacing and to provide support.

E. Neutral Conductors

1. Neutral conductors that are effectively grounded throughout their length and associated with circuits of 0 to 22 kV to ground may have the same clearances as guys and messengers.
2. All other neutral conductors of supply circuits shall have the same clearances as the phase conductors of the circuit with which they are associated.

F. Fiber-Optic Cable

1. Fiber-optic—supply cable
   a. Cable defined as "fiber-optic—supply" supported on a messenger that is effectively grounded throughout its length shall have the same clearance from communications facilities as required for a neutral conductor meeting Rule 230E1.
   b. Cable defined as "fiber-optic—supply" that is entirely dielectric, or supported on a messenger that is entirely dielectric, shall have the same clearance from communications facilities as required for a neutral conductor meeting Rule 230E1.
   c. Fiber-optic—supply cables supported on or within messengers not meeting Rule 230F1a or 230F1b shall have the same clearances from communications facilities required for such messengers.
   d. Fiber-optic—supply cables supported on or within a conductor(s), or containing a conductor(s) or cable sheath(s) within the fiber-optic cable assembly shall have the same clearances from communications facilities required for such conductors. Such clearance shall be not less than that required under Rule 230F1a, 230F1b, or 230F1c, as applicable.
   e. Fiber-optic—supply cables meeting Rule 224A3 are considered to be communication cables when located in the communication space.
2. Fiber-optic—communication cable

   Cable defined as "fiber-optic—communication" shall have the same clearance from supply facilities as required for a communication messenger.

G. Alternating- and Direct-Current Circuits

The rules of this section are applicable to both ac and dc circuits. For dc circuits, the clearance requirements shall be the same as those for ac circuits having the same crest voltage to ground.

ft

Table 232-1

Vertical Clearance of Wires, Conductors, and Cables Above Ground, Roadway, Rail or Water Surfaces[25]

(Voltages are phase to ground for effectively grounded circuits and those other circuits where all ground faults are cleared by promptly de-energizing the faulted section, both initially and following subsequent breaker operations. See the definitions section for voltages of other systems. See Rules 232B1, 232C1a, and 232D4.)

Nature of surface underneath wires, conductors, or cables	Insulated communication conductors and cable; messengers; surge-protection wires; grounded guys and ungrounded guys exposed to 0 to 300 V[11, 15]; neutral conductors meeting Rule 230E1; supply cables meeting Rule 230C1 (ft)	Noninsulated communication conductors; supply cables of 0 to 750 V meeting Rules 230C2 or 230C3 (ft)	Supply cables over 750 V meeting Rules 230C2 or 230C3; open supply conductors, 0 to 750 V; ungrounded guys exposed to over 300 V to 750 V[14] (ft)	Open supply conductors, over 750 V to 22 kV; ungrounded guys exposed to 750 V to 22 kV[14] (ft)	Trolley and electrified railroad contact conductors and associated span or messenger wires	
					0 to 750 V to ground (ft)	Over 750 V to 22 kV to ground (ft)
Where wires, conductors, or cables cross over or overhang						
1. Track rails of railroads (except electrified railroads using overhead trolley conductors)[2, 16, 20]	23.5	24.0	24.5	26.5	22.0[4]	22.0[4]
2. Roads, streets, and other areas subject to truck traffic[21]	15.5	16.0	16.5	18.5	18.0[5]	20.0[5]
3. Driveways, parking lots, and alleys	15.5[7, 13]	16.0[7, 13]	16.5[7]	18.5	18.0[5]	20.0[5]
4. Other land traversed by vehicles, such as cultivated, grazing, forest, orchards, etc.[25]	15.5	16.0	16.5	18.5	—	—
5. Spaces and ways subject to pedestrians or restricted traffic only[9]	9.5	12.0[8]	12.5[8]	14.5	16.0	18.0
6. Water areas not suitable for sailboating or where sailboating is prohibited[19]	14.0	14.5	15.0	17.0	—	—
7. Water areas suitable for sailboating including lakes, ponds, reservoirs, tidal waters, rivers, streams, and canals with an unobstructed surface area of[17, 18, 19]						
a. Less than 20 acres	17.5	18.0	18.5	20.5	—	—
b. Over 20 to 200 acres	25.5	26.0	26.5	28.5	—	—
c. Over 200 to 2000 acres	31.5	32.0	32.5	34.5	—	—
d. Over 2000 acres	37.5	38.0	38.5	40.5	—	—

Table 232-1 *(Continued)*

Vertical Clearance of Wires, Conductors, and Cables Above Ground, Roadway, Rail or Water Surfaces[25]

(Voltages are phase to ground for effectively grounded circuits and those other circuits where all ground faults are cleared by promptly de-energizing the faulted section, both initially and following subsequent breaker operations. See the definitions section for voltages of other systems. See Rules 232B1, 232C1a, and 232D4.)

Nature of surface underneath wires, conductors, or cables	Insulated communication conductors and cable; messengers; surge-protection wires; grounded guys and ungrounded guys exposed to 0 to 300 V [11, 15]; neutral conductors meeting Rule 230E1; supply cables meeting Rule 230C1 (ft)	Noninsulated communication conductors; supply cables of 0 to 750 V meeting Rules 230C2 or 230C3 (ft)	Supply cables over 750 V meeting Rules 230C2 or 230C3; open supply conductors, 0 to 750 V; ungrounded guys exposed to over 300 V to 750 V[14] (ft)	Open supply conductors, over 750 V to 22 kV; ungrounded guys exposed to 750 V to 22 kV[14] (ft)	Trolley and electrified railroad contact conductors and associated span or messenger wires	
					0 to 750 V to ground (ft)	Over 750 V to 22 kV to ground (ft)
8. Public or private land and water areas posted for rigging or launching sailboats	Clearance above ground shall be 5 ft greater than in 7 above, for the type of water areas served by the launching site					
Where wires, conductors, or cables run along and within the limits of highways or other road rights-of-way but do not overhang the roadway						
9. Roads, streets, or alleys	15.5[13, 24]	16.0[13]	16.5	18.5	18.0[5]	20.0[5]
10. Roads in rural districts where it is unlikely that vehicles will be crossing under the line	13.5[10, 12]	14.0[10]	14.5[10]	16.5	18.0[5]	20.0[5]

[1] Where subways, tunnels, or bridges require it, less clearance above ground or rails than required by Table 232-1 may be used locally. The trolley and electrified railroad contact conductor should be graded very gradually from the regular construction down to the reduced elevation.

[2] For wires, conductors, or cables crossing over mine, logging, and similar railways that handle only cars lower than standard freight cars, the clearance may be reduced by an amount equal to the difference in height between the highest loaded car handled and 20 ft, but the clearance shall not be reduced below that required for street crossings.

[3] This footnote not used in this edition.

[4] In communities where 21 ft has been established, this clearance may be continued if carefully maintained. The elevation of the contact conductor should be the same in the crossing and next adjacent spans. (See Rule 225D2 for conditions that must be met where uniform height above rail is impractical.)

[5] In communities where 16 ft has been established for trolley and electrified railroad contact conductors 0 to 750 V to ground, or 18 ft for trolley and electrified railroad contact conductors exceeding 750 V, or where local conditions make it impractical to obta in the clearance given in the table, these reduced clearances may be used if carefully maintained.

[6] This footnote not used in this edition.

[7] Where the height of a building or other installation does not permit service drops to meet these values, the clearances over residential driveways only may be reduced to the following:

	(feet)
(a) Insulated supply service drops limited to 300 V to ground	12.5
(b) Insulated drip loops of supply service drops limited to 300 V to ground	10.5
(c) Supply service drops limited to 150 V to ground and meeting Rules 230C1 or 230C3	12.0
(d) Drip loops only of service drops limited to 150 V to ground and meeting Rules 230C1 or 230C3	10.0
(e) Insulated communication service drops	11.5

[8] Where the height of a building or other installation does not permit service drops to meet these values, the clearances may be reduced to the following:

	(feet)
(a) Insulated supply service drops limited to 300 V to ground	10.5
(b) Insulated drip loops of supply service drops limited to 300 V to ground	10.5
(c) Supply service drops limited to 150 V to ground and meeting Rules 230C1 or 230C3	10.0